2-Phase™ Vacuum Extraction and Vapor Phase Biotreatment Treatability Study Test Design

FE Warren Air Force Base
Cheyenne, Wyoming

August 1995

Prepared for:

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14. ABSTRACT
This report is the work plan for a test of the high vacuum 2-PHASE? Extraction (2-Phase) process for the removal of trichloroethene (TCE) in soil and groundwater that was conducted at F.E. Warren Air Force Base (AFB), Wyoming. TCE offgased from the 2-Phase system was treated using a vapor phase bioreactor. Dual phase and pump and treat extraction were also tested for comparison to the 2-Phase system to determine which system would be most suitable for use at F.E. Warren AFB. The integration of the 2-Phase system with the vapor-phase bioreactor was successful. Greater than 95% of dissolved TCE in groundwater was stripped into the vapor-phase by the 2-Phase process. Activated carbon was used to remove the small residual. Groundwater concentrations ranged from 100-1000 ?g/L during the test. The gas-phase reactor demonstrated 85% to 90% TCE removal efficiencies at inlet TCE concentrations ranging from 10-700 ?g/L (@17.7 psia and 150 deg F). Because the comparison objective was added to the scope after the Treatability Study Test Design was complete, it was not possible to make definitive comparisons between the three system types due to the evolution of the scope of the project. However, based on this test, process knowledge and experiences at other sites the following conclusions were drawn: 2-Phase is likely to be more cost effective in tighter formations, and pump and treat or traditional (low vacuum) dual phase is likely to be more cost effective in more productive formations.

15. SUBJECT TERMS
trichloroethene, trichloroethylene, TCE, DNAPL, groundwater remediation, soil remediation, bioreactor, treatability study, dual-phase, 2-PHASE Extraction, F. E. Warren AFB, pump and treat

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2-PHASE VACUUM EXTRACTION AND VAPOR PHASE BIOTREATMENT TREATABILITY STUDY TEST DESIGN

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ACRONYMS

AFB	Air Force Base
CFR	Code of Federal Regulations
DCE	Dichloroethylene
EPA	U.S. Environmental Protection Agency
EZ	Exclusion Zone
GC	Gas Chromatography
GPR	Gas-Phase Reactor
PPE	Personal Protective Equipment
OSHA	Occupational Safety and Health Administration
OU	Operable Unit
QAPP	Quality Assurance Project Plan
QA	Quality Assurance
QC	Quality Control
SSHP	Site Safety and Health Plan
SVOC	Semivolatile Organic Compound
TCE	Trichloroethylene
VOC	Volatile Organic Compound

1.0 INTRODUCTION

This work plan describes a 61-day, pilot-scale treatability study to be performed at FE Warren Air Force Base (AFB), Wyoming, Operable Unit 2 (OU 2) to support the evaluation of 2-PHASE vacuum extraction and vapor-phase bioreactor treatment of trichloroethylene (TCE) in soil and groundwater.

This work plan is a supplement to the Quality Assurance Project Plan (QAPP) for the remedial investigation at FE Warren AFB. This document and all activities associated with this pilot test will be performed in accordance with the QAPP.

OU 2 is the site of TCE plume "C." The data collected from previous investigations in OU 2 have been used to characterize the subsurface features and the nature and relative extent of contamination at the site. Groundwater contamination has resulted from previous waste practices and is migrating east. The primary contaminant of interest is TCE. The subsurface has low permeability and consists of sandy clay, clay, silty clay, and silty sand.

In an effort to identify feasible extraction and treatment alternatives for the Air Force, the Air Force Center for Environmental Excellence and FE Warren AFB would like to demonstrate the effectiveness of 2-PHASE vacuum extraction and vapor-phase biotreatment for removing chlorinated contaminants from the subsurface.

The 2-PHASE vacuum extraction technology has been shown to be a highly effective technology for extracting volatile organic compounds (VOCs) from low to moderate permeability soils similar to those found at this site. The 2-PHASE system simultaneously extracts contaminants from groundwater and soil using a high vacuum. Due to the turbulence and low absolute pressure created by the applied vacuum, VOCs present in extracted groundwater volatilize and partition into the vapor phase along with the VOCs extracted from the soil. The extracted mixture of air and entrained water enters a separator on the surface where the liquid and vapor phases are separated, treated, and discharged.

ENVIROGEN's Gas-Phase Reactor (GPR) has been shown to be effective at removing TCE and other chlorinated vapor contaminants from air streams. ENVIROGEN's GPR is designed to optimize the conditions necessary to biologically degrade TCE and other vapor contaminants requiring co-substrates for treatment. Biological treatment of chlorinated VOCs offers a cost-effective treatment option compared to conventional adsorptive and thermal processes. Other advantages of vapor-phase biotreatment include:

- destruction of extracted pollutants yielding harmless by-products;
- on-site removal and degradation compared to adsorptive processes requiring off-site regeneration; and
- no generation of NO_x, SO_x, carbon monoxide, or thermal pollution.

This pilot study will provide site-specific contaminant removal data and subsurface response data to be applied toward the evaluation of 2-PHASE vacuum extraction combined with vapor-phase biotreatment as a remedial technology. The primary objectives of this short-term, pilot-scale test are to demonstrate the contaminant removal, treatment effectiveness, and compatibility of the 2-PHASE vacuum extraction and vapor-phase biotreatment technologies.

The evaluation of the 2-PHASE vacuum extraction and vapor-phase biotreatment (GPR) technologies will be based on a review of analytical data and field measurements collected prior to, during, and after the test. Groundwater contaminant concentrations will be measured in samples collected from the extraction well prior to and after the test. Liquid and vapor contaminant concentrations will be measured in the liquid and vapor extracted from the subsurface at various times throughout the test. Vapor-phase contaminant concentrations will be measured at the influent and effluent of the bioreactor. Liquid and vapor throughput and nutrient addition will also be monitored.

Field measurements for the 2-PHASE vacuum extraction system include extracted liquid and vapor flow rates, groundwater drawdown, and the extent of magnitude of vacuum influence. Field measurements for the GPR include influent and effluent vapor contaminant concentrations, vapor throughput, nutrient levels, and intrinsic TCE biodegradation capacity. Operational data for the 2-PHASE vacuum extraction and vapor-phase bioreactor equipment will also be recorded for the duration of the test. These data will be used to refine the subsurface conceptual model for 2-PHASE vacuum extraction, optimize the operating conditions of the vapor-phase bioreactor, and provide detailed information to evaluate the compatibility of these two remedial technologies.

In addition to fulfilling the objectives above, the data gathered from this test will provide information needed to support the selection of a remedial technology for this site. namely 2-phase

All applicable data collected during the test can be used to select and design a full-scale extraction and biological treatment system for this site.

2.0 TECHNOLOGY DESCRIPTION

The following sections describe the technologies to be demonstrated during this pilot test.

2.1 2-PHASE Vacuum Extraction

The 2-PHASE vacuum extraction process was developed for the remediation of VOCs and other contaminants in low to moderate permeability subsurface formations. The process is a modification of conventional vacuum extraction employing a high-vacuum pump and a small diameter suction pipe (straw) installed into a larger diameter extraction well. The lower end of the straw is set at the desired groundwater drawdown depth, usually within inches of the total well depth, and the wellhead is sealed. High vacuum (approximately 18 to 26 in. of mercury) is applied to the straw, causing vapor in the well to be drawn into the pipe at a high velocity. Liquid (groundwater and contaminants) present in the well bore is aspirated into small droplets by the high velocity flow and becomes entrained in the vapor. The vapor consists of soil vapor drawn in from the surrounding formation and, during startup, air introduced at the wellhead (aspiration air) to enhance liquid entrainment. Figure 2-1 shows the proposed plot plan of the site. Figure 2-2 shows a diagram of the 2-PHASE well to be used for the test.

Vapor and entrained liquid from the extraction well are conveyed under vacuum up the straw and through a flexible hose toward the vacuum source. The extreme turbulence in the formation, straw, and hose facilities transfers volatile compounds from the liquid phase to the vapor phase. The contaminant transfer process employs many of the same principles used in conventional air strippers. The applied vacuum, or low absolute pressure in the system, enhances contaminant transfer by increasing the volatilization of contaminants. The hose is connected to a separation canister installed immediately upstream of the vacuum pump. The canister separates the entrained liquid from the vapor so that each phase can be treated and discharged separately. The vapor will be treated using the bioreactor. Liquid will be polished with activated carbon and discharged to a temporary storage tank.

2-PHASE vacuum extraction removes liquid, vapor, and adsorbed contaminants from soil at a high rate and subjects a large soil volume to treatment, which can substantially reduce the overall time needed for site remediation. The vacuum applied to the extraction well increases liquid flow to the well, lowers the water table, and evacuates liquid from the area around the well. As the water table is lowered, more of the soil formation is exposed to vacuum, causing vapor flow to the well to increase. Vapor, having a much lower effective viscosity than water, is pulled through the formation at a high rate. The vapor flow volatilizes adsorbed and free phase contaminants from both the vadose zone and formerly saturated soils and removes them in the vapor phase.

2.2 Vapor-Phase Bioreactor Treatment

The plot plan of ENVIROGEN's field-pilot TCE GPR system is shown in Figure 2-3. The field-pilot bioreactor system is comprised of the bioreactor vessel with automatic pH, foam, and temperature control (a heating element and a refrigerated cooling coil), nutrient (salts and caustic) feeds, and a discharge tank. A blower delivers contaminated vapor to the bottom of the bioreactor. The vapor is then vigorously

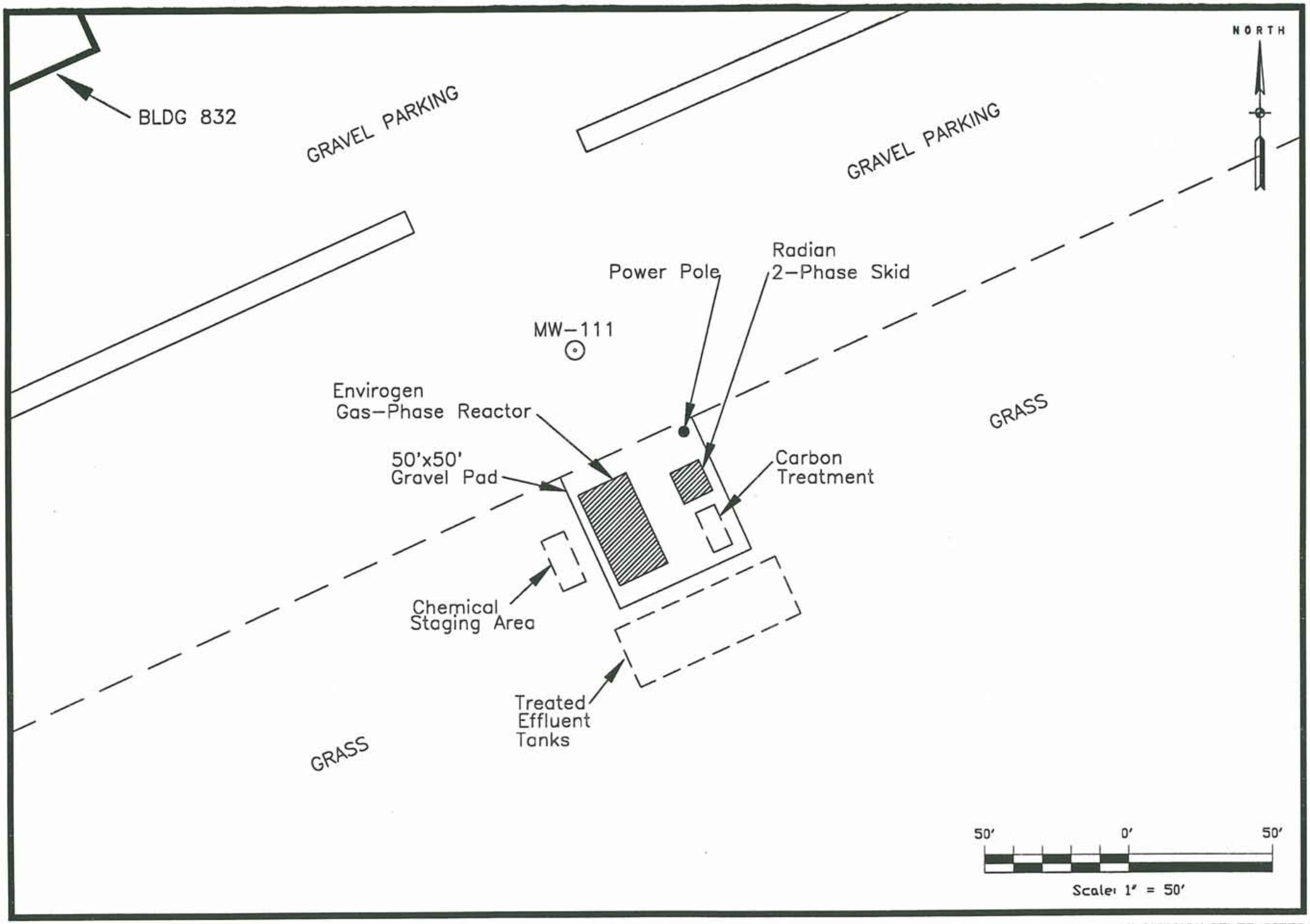

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Figure 2-1. Site Plot Plan

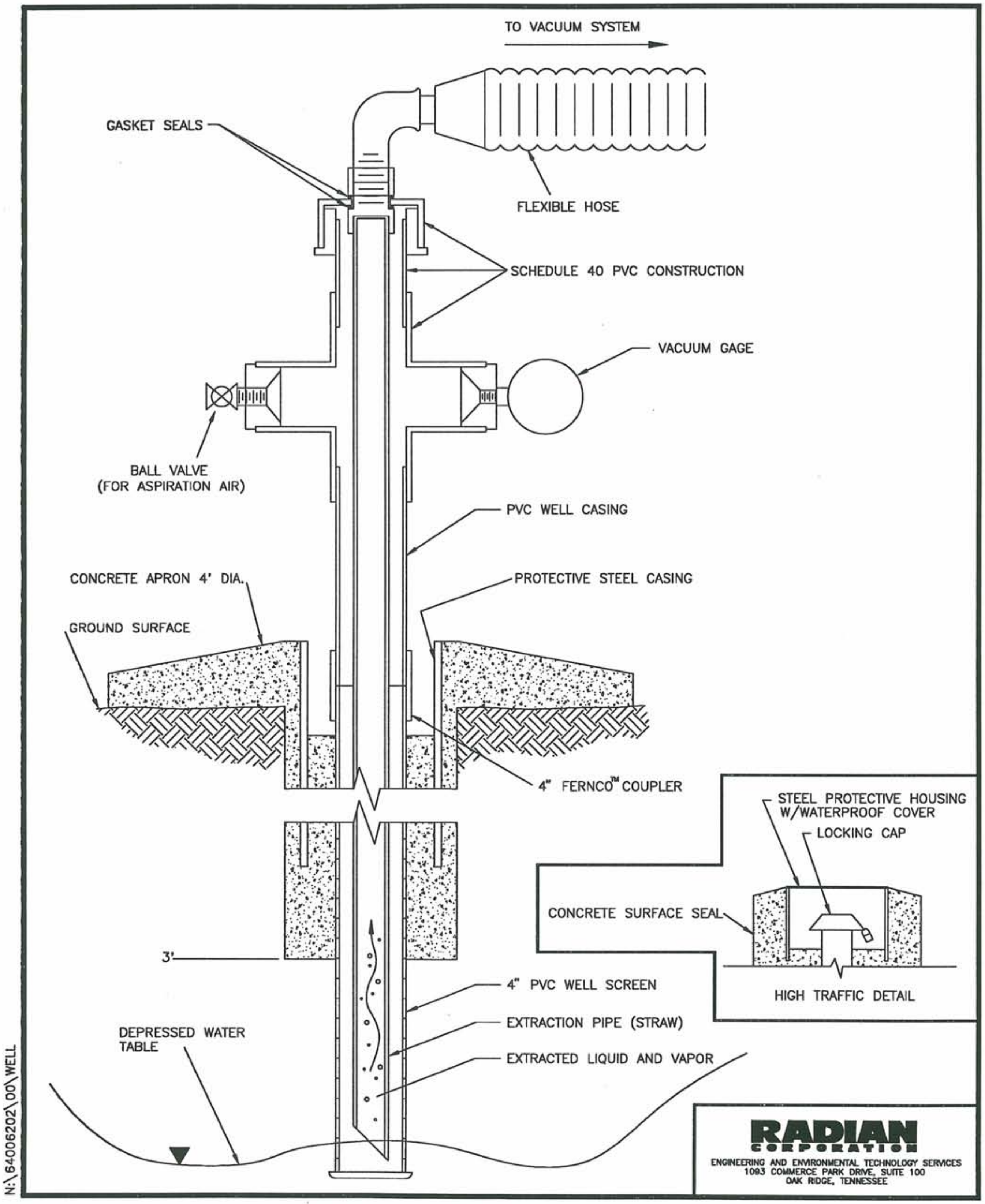

Figure 2-2. 2-PHASE Wellhead Assembly and Extraction Well

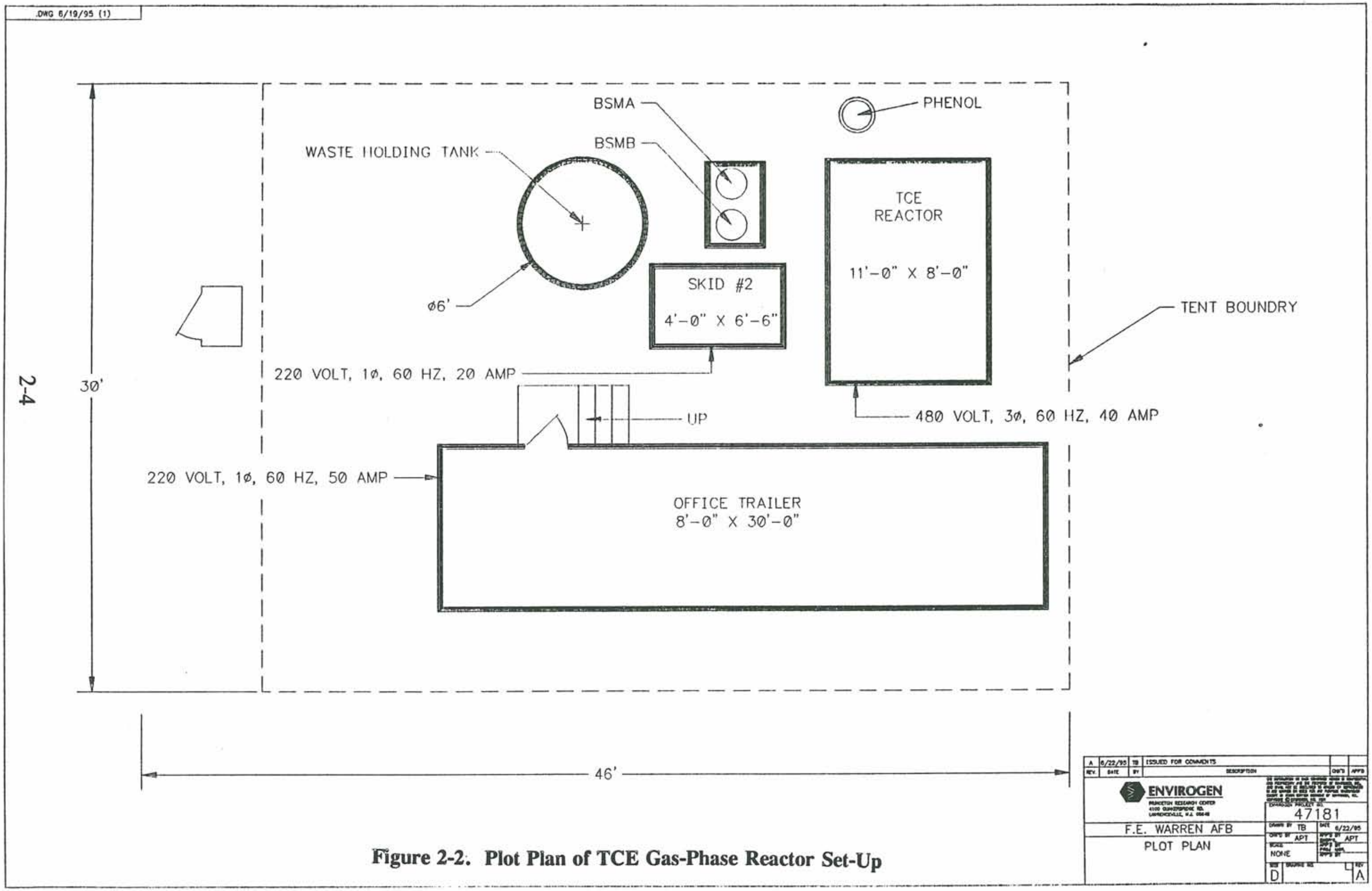

Figure 2-2. Plot Plan of TCE Gas-Phase Reactor Set-Up

mixed with the vessel's liquid contents, which supports the growth of the degradative bacteria. As the vapor bubbles upward through the liquid column, TCE and other chlorinated contaminants are transferred from the vapor to the liquid where they are destroyed by the bacteria.

The treated vapor leaves the liquid at the top of the water column and exits the reactor. Nutrients and phenol, a growth substrate for the TCE degradative bacteria, are metered into the reactor with a small volume of make-up water. Wastewater exits the reactor after passing over an overflow weir. The wastewater contains excess biomass and salts that can typically be discharged to a sanitary water treatment system. A holding tank is used to allow for batch disposal of wastewater following optional analysis. A gas chromatography system equipped with electron capture and flame ionization detectors is employed to automatically quantify concentrations of selected organic contaminants in the feed and treated effluent streams.

ENVIROGEN's field-pilot GPR has been shown to be effective at treating inlet TCE concentrations up to 500 μg/L ($\sim$100 ppmv). Vapor flow rates up to 30 scfm can be processed through the system. A wide variety of halogenated and nonhalogenated VOCs can be degraded using the GPR. Treatment of contaminants such as TCE, dichloroethylene (DCE), vinyl chloride, and benzene, toluene, ethylbenzene, and xylene have been demonstrated using a bench-scale prototype. Multiple seed cultures can be used for treating complex waste streams. The bioreactor is easily transported for remote applications and can be used both indoors and outdoors.

3.0 PILOT TEST APPARATUS DESCRIPTION

A schematic of the equipment to be used for the pilot test is presented in Figures 3-1, 3-2a, and 3-2b. The equipment includes the extraction well, wellhead assembly, mobile 2-PHASE vacuum extraction system, skid-mounted bioreactor system and off-skid ancillary equipment, skid #2 of biotreatment system containing sumps and transfer pumps, liquid-phase activated carbon treatment, and liquid storage tank.

A new extraction well will be used for the demonstration. This site is appropriate for the demonstration for the following reasons:

- The site is underlain with a combination of VOCs, including chlorinated solvents, which are present in the saturated and unsaturated zones.
- The formation has a relatively low hydraulic conductivity (slug tests of existing wells indicate an average hydraulic conductivity of 1.0×10^{-3} cm/sec).
- The total depth of the proposed well (23 ft) is within the proven range for 2-PHASE.
- The screen on the proposed well will extend above and below the static water table.
- Contaminant concentrations are within the proven range for treatment by the bioreactor.
- Contaminant concentrations will facilitate cost analysis of a full-scale application of these technologies.

The wellhead assembly will be fabricated in the field similar to that shown in Figure 2-2. A 2 in. diameter PVC pipe will be attached to the wellhead and convey extracted contaminants to the vacuum system.

3.1 2-PHASE Vacuum System

A mobile 2-PHASE vacuum extraction system owned by Radian Corporation will be delivered to FE Warren AFB for use during the technology demonstration. It is trailer-mounted and includes a liquid/vapor separator, liquid ring vacuum pump, extracted liquid transfer pump, seal fluid separator and reservoir, and a vapor aftercooler (Figure 3-1). The system is semi-automated and includes level sensors for all fluid vessels, temperature and vacuum gauges, and a fail-safe control system. It is powered by a single 230-volt, three-phase electrical connection, rated at 60 amps.

3.2 Vapor-Phase Bioreactor System

A skid-mounted TCE GPR system owned by ENVIROGEN will be delivered to FE Warren AFB for use during the technology demonstration. Schematics of the field-pilot GPR system are shown in Figures 3-2a and 3-2b.

ENVIROGEN's field-pilot GPR system has approximate dimensions of 8 × 11 × 11 ft and weighs about 10,000 lb. The bioreactor vessel (R-101) is approximately 6 ft in diameter and 10 ft tall and holds approximately 750 gal of liquid. The system is operated in a stirred-tank mode using a mixer (M-102) to facilitate mass transfer. The

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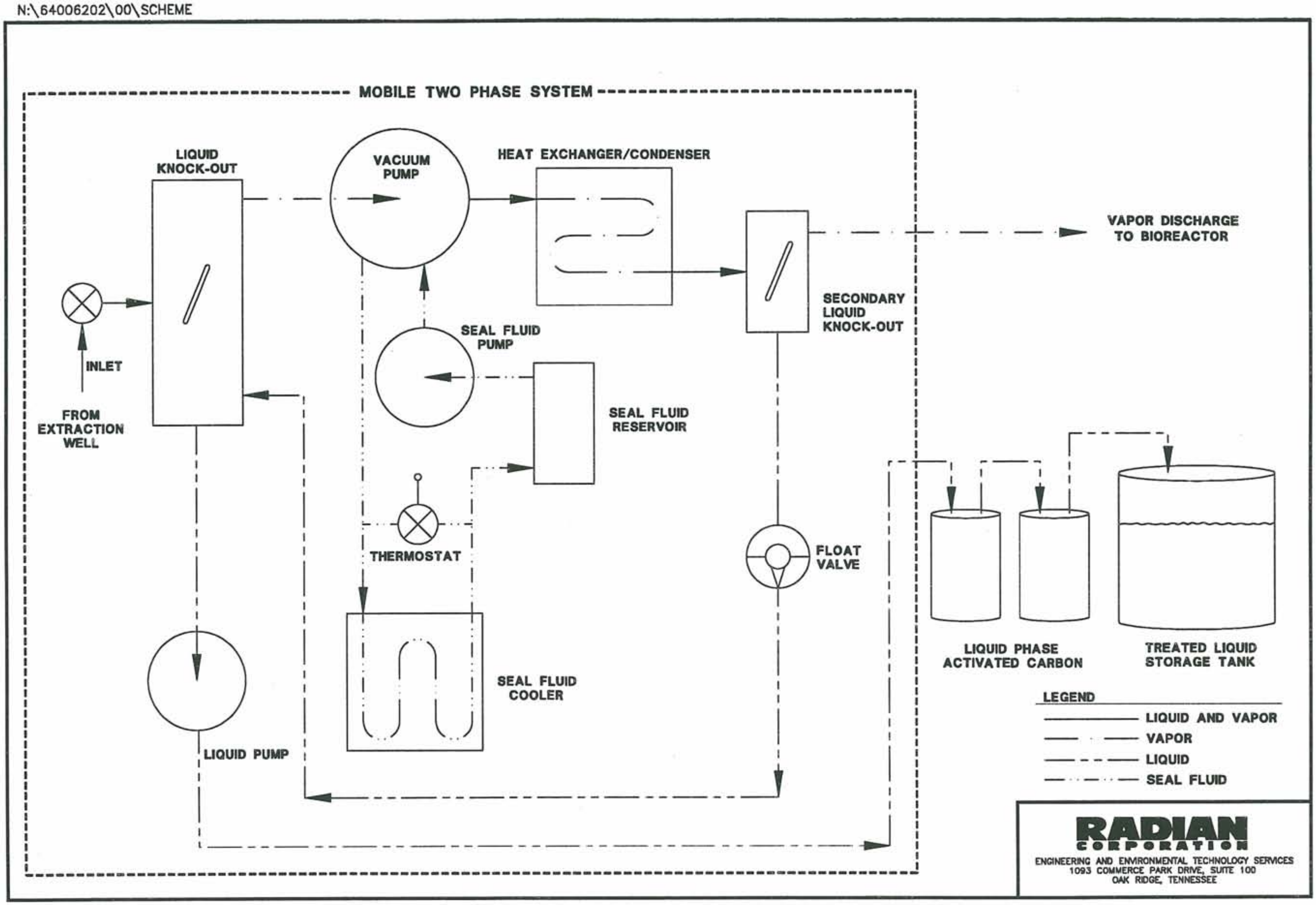


Figure 3-1. 2-PHASE Vacuum Extraction Apparatus Schematic

equipment requires three-phase, 230-volt power rated at 80 amps. The vessel and piping are constructed from either carbon or stainless steel to minimize fugitive emissions and provide compatibility with a wide range of chemicals. System pH is automatically controlled using caustic. The system has two on-skid (T-101 and T-102) and two off-skid (BSMB and BSMA) chemical feed systems for the addition of caustic and nutrients. Reactor water temperature is controlled through an on-skid heater and refrigeration system.

The system is capable of handling up to 30 cfm of air flow, depending on the specific contaminants and concentrations present. The vapor effluent from the 2-PHASE vacuum extraction system aftercooler will be piped to the GPR system using a 3 in. PVC pipe at the Stream #1 location shown in Figure 3-2a.

If concentrations exceeding the design capabilities of the system are observed, the vapor inlet stream can be diluted (Stream #2 shown in Figure 3-2a). Sample ports are located a key points throughout the system, including gas influent, gas effluent, and liquid from the reactor vessel. An automated gas chromatography (GC) system will be used to continually monitor the feed and effluent air streams. In addition to the bioreactor influent and effluent streams, the discharge from the 2-PHASE vacuum extraction system (before dilution), and the discharge from the vapor-phase polishing canisters, will also be routinely monitored.

An off-skid by-product holding tank, T-104, which has 1250 gal of capacity, will be used for temporary batch storage of bioreactor wastewater. This wastewater will be treated with bleach to kill any residual biomass. In addition, the wastewater will be sampled and characterized to ensure that it is safe for disposal. A local hauling contractor will be used to transport the treated water for disposal during the test. A second by-product holding tank will be on-site for use while the contents of the primary holding tank are being analyzed.

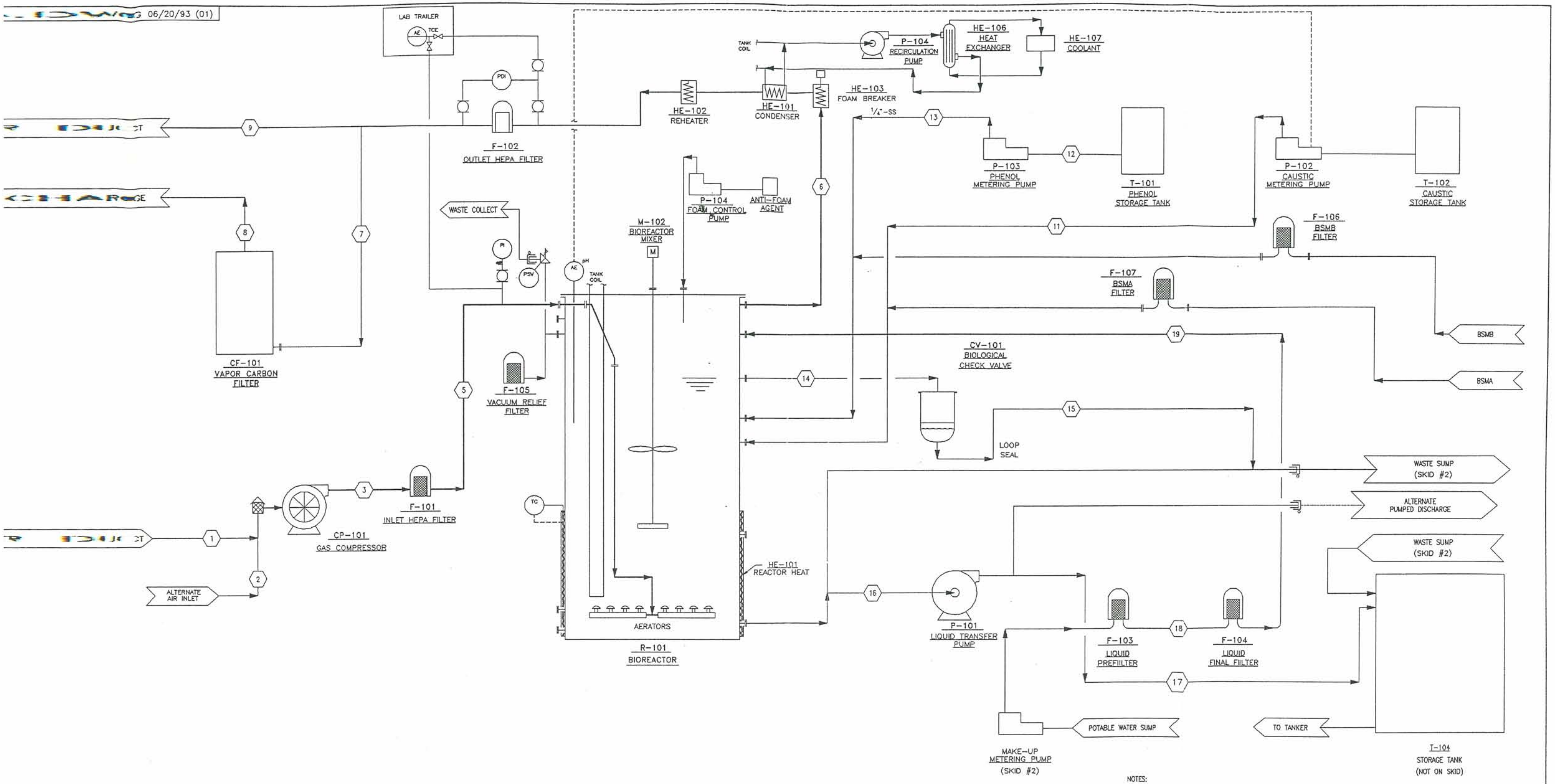
A sump to transfer wastewater discharge from the bioreactor to the wastewater holding tank will be provided on a second skid designated Skid #2. This skid also contains a transfer pump for supplying make-up water to the GPR system. Skid #2 requires a single-phase, 220-volt power source rated at 20 amps.

3.3 Other Equipment

Two liquid-phase activated carbon drums will be purchased from Westates Carbon for the treatment of extracted liquid. The carbon drums will be connected in series to ensure adequate treatment. After the test, the carbon will be characterized and returned to Westates for disposal. Since the carbon will contain solvents, it will be managed as hazardous waste and will be manifested by the Base. This will be coordinated with the Base Hazardous Waste Coordinator.

Rented portable tanks will be used to store treated groundwater from the 2-PHASE system. This water will be sampled and characterized to ensure adequate treatment. It is estimated that up to 100,000 gal of treated groundwater may be generated.

A rental office trailer will be used for ENVIROGEN's on-site analytical vapor monitoring equipment and personnel. This trailer will require a single-phase, 220-volt power source rated at 50 amps.



NOTES:
(1) FLOW IS INTERMITTENT
(2) N.A. MEANS NOT APPLICABLE

Figure 3-2a. 3-3

[illegible]AM NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
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[illegible]	4 SCFM	0 SCFM	4 SCFM	0 SCFM	4 SCFM	4 SCFM	4 SCFM	4 SCFM	0 SCFM	___	___	___	___	___	___	50 GPM (1)	20-50 GPM (1)	20 GPM (1)	20 GPM (1)
	0.36	0	0.36	0	0.36	___	___	0	___	0	0	0	0	___	___	___	___	0	0
	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	3.0	3.0	3.0	3.0	0	0
	+1" W.C.	0	5 PSIG	0-5 PSIG	5 PSIG	+4" W.C.	+2" W.C.	0" W.C.	+1" W.C.	0	2 PSIG	0	25 PSIG	+4" W.C.	0	4 PSIG	4 PSIG	19 PSIG	4 PSIG
[illegible] (°F)	70	70	150	70	150	77	85	85	85	60	60	60	60	77	77	60	60	60	60
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TCE VAPOR PHASE PROCESS FLOW DIAGRAM

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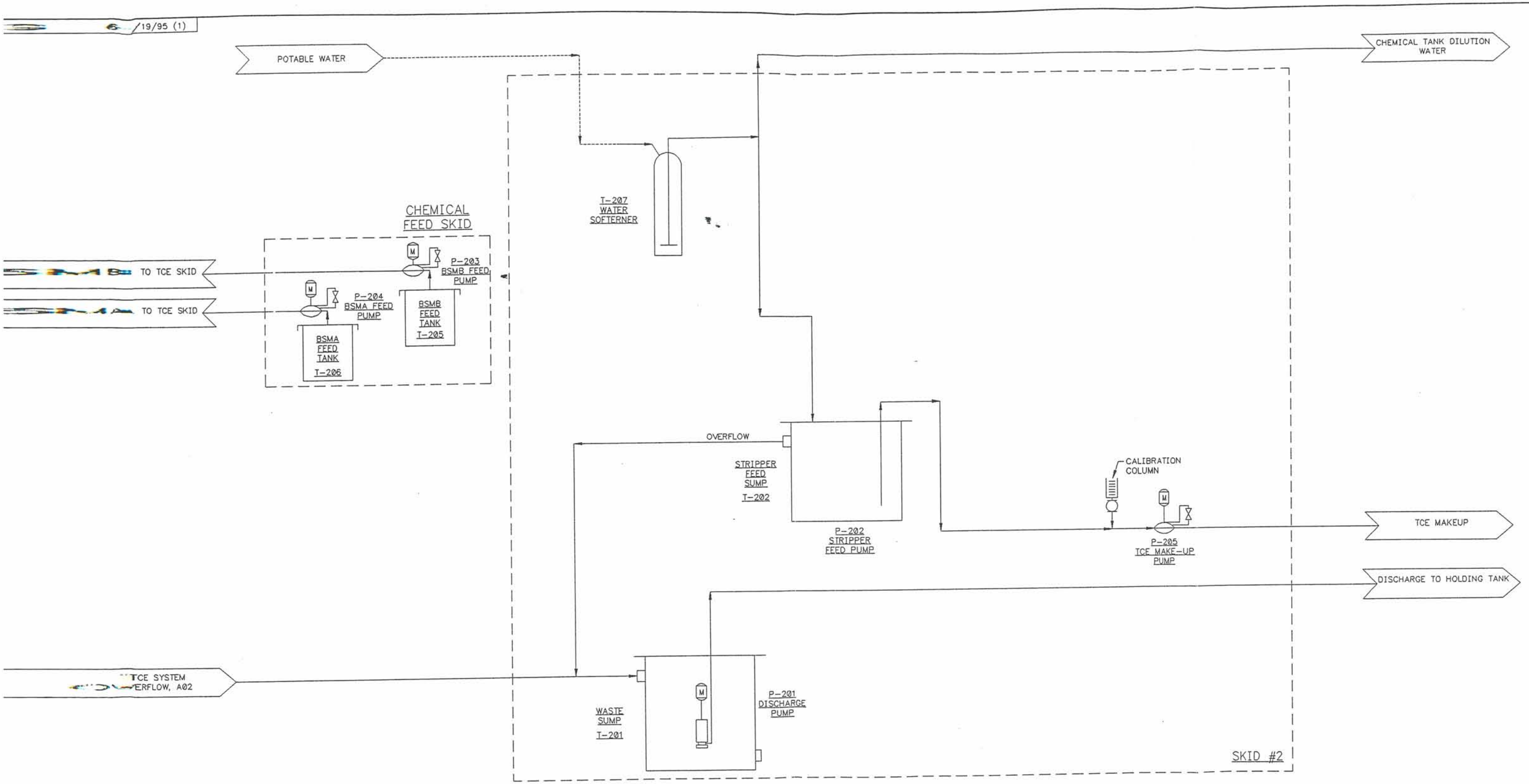

Figure 3-2b.

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SKID #2
FLOW DIAGRAM

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SCALE: NONE | APP'D BY PROJ. MGR.
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SIZE D | DRAWING NO. 47181C02 | REV. A

4.0 TESTING PROCEDURES

The pilot-scale test of 2-PHASE vacuum extraction followed by vapor-phase VOC bioreactor treatment will consist of a 61-day test to be conducted at OU 2. The primary VOC of interest is TCE. All activities (equipment monitoring, sample collection, sample control, and sample analysis) will be conducted in accordance with the procedures and protocols described in the U.S. Environmental Protection Agency (EPA)-approved FE Warren AFB QAPP, the Site Safety and Health Plan (SSHP) included in Section 8.0, and the FE Warren AFB SSHP.

4.1 Extraction Well and Monitoring Points Installation

A groundwater extraction well will be installed to a depth of 23 ft. The well will be installed near existing monitor well no. 111 using a hollow stem auger. The screen on the well will penetrate both the vadose zone and the saturated zone. The well will be a 4-in. PVC type that is constructed for use in severe weather. The well will be finished with a flush mount cap and a concrete pad. The installation of this well will be in accordance with the approved FE Warren Field Sampling Plan dated January 1992.

An array of six piezometers and six vapor probes will be installed around the extraction well to assess the performance of the 2-PHASE system. Existing monitor well no. 111 will be used as one of the piezometers. Piezometers and vapor probes will be installed using a hollow-stem auger drilling rig in accordance with the FE Warren AFB QAPP. A piezometer and vapor probe construction cross-section is shown in Figure 4-1. Liquid piezometers will penetrate the saturated zone and will be screened below the static water table to a depth of 25 ft. The vapor probe will extend to the full depth of the unsaturated zone.

Figure 4-2a shows a plan view and Figure 4-2b shows a side view of the extraction well, the piezometers, and the vapor probes. The piezometers will be used to monitor groundwater drawdown during the test. Groundwater levels will be measured using a battery-powered water level meter. The vapor probes will be used to monitor the extent and magnitude of vacuum influence on the soil formation. The piezometers will also be used to measure vacuum in the clay intervals as the zones become unsaturated during the test. Applied vacuum will be measured using a Magnehelic™ pressure gauge.

4.2 Equipment Mobilization and Test Setup

The following equipment and materials will be mobilized to the OU 2 site in preparation for the pilot test. All equipment and materials will be available on-site the week prior to the test.

4.2.1 2-PHASE Equipment Mobilization

The 2-PHASE vacuum extraction system will be towed to the site and spotted near the extraction well. The wellhead will be installed. Activated carbon and portable storage tanks will also be delivered to the site.

The following steps will be performed to set up for the pilot test. The duration for the setup is estimated to be five days.

- Spot all equipment on the site. Rope off the site to restrict access. Establish a location for vehicles and materials.

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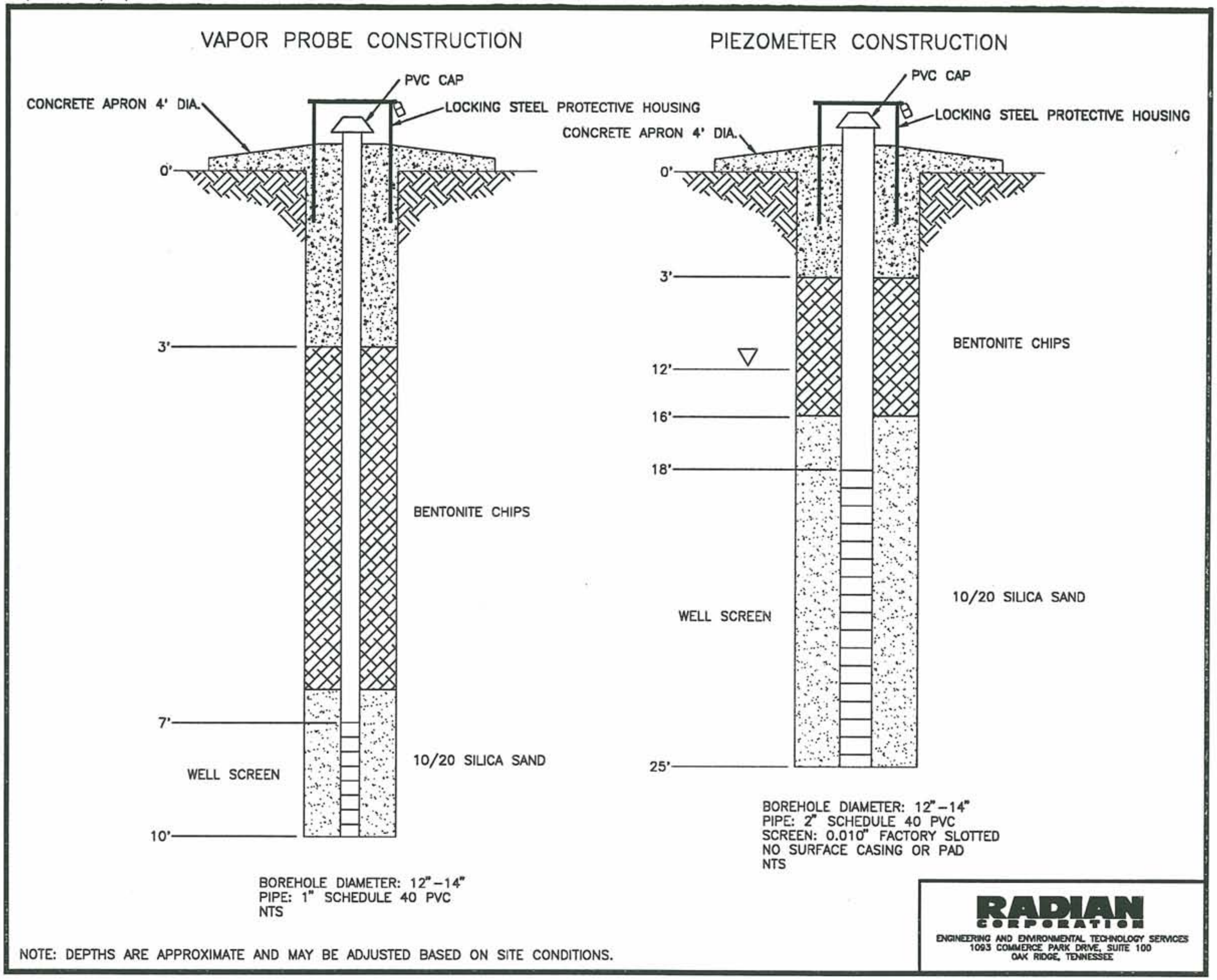

Figure 4-1. Piezometer and Vapor Probe Construction Cross-Section

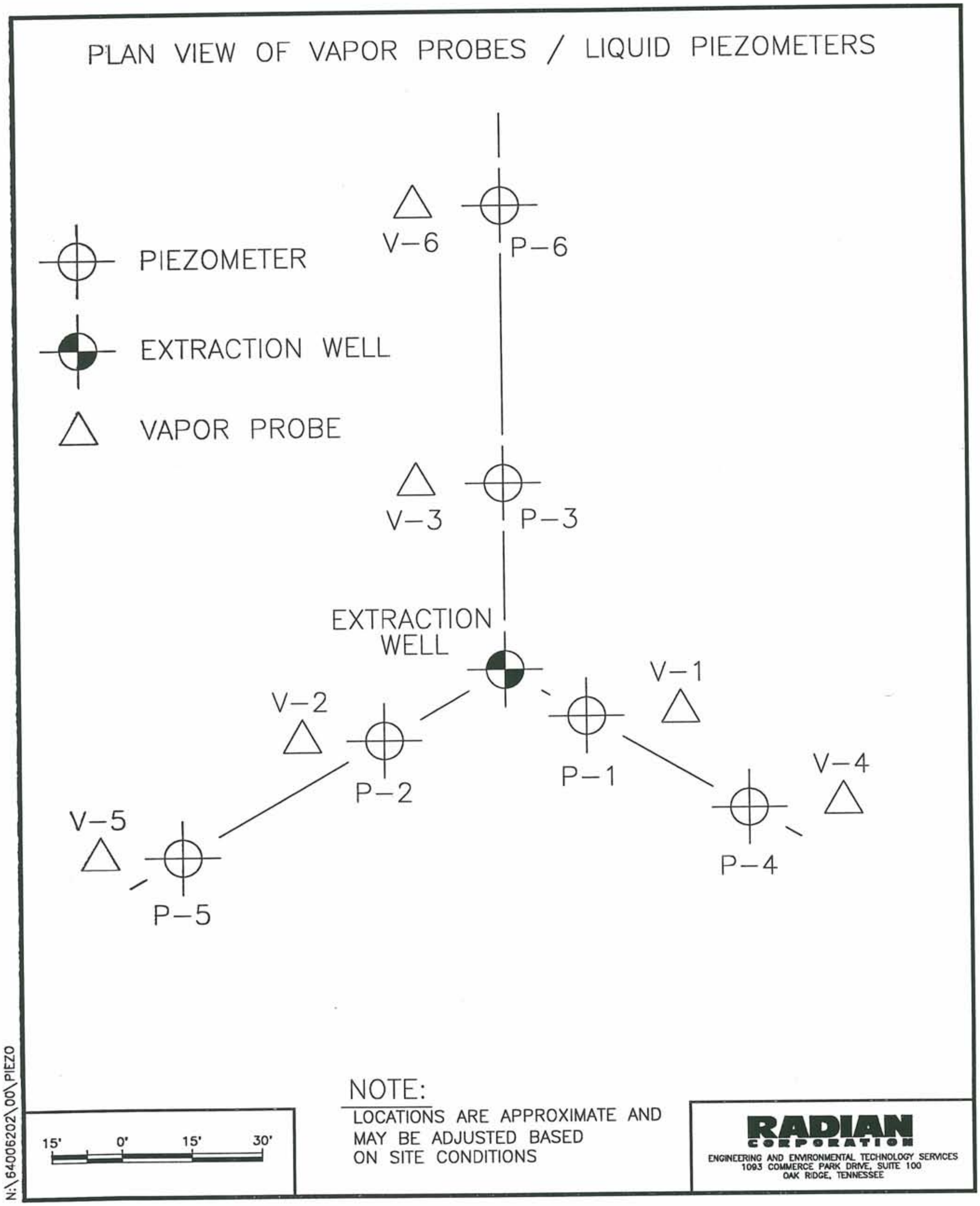

Figure 4-2a. Extraction Well, Piezometer, and Vapor Probe Layout (plan view)

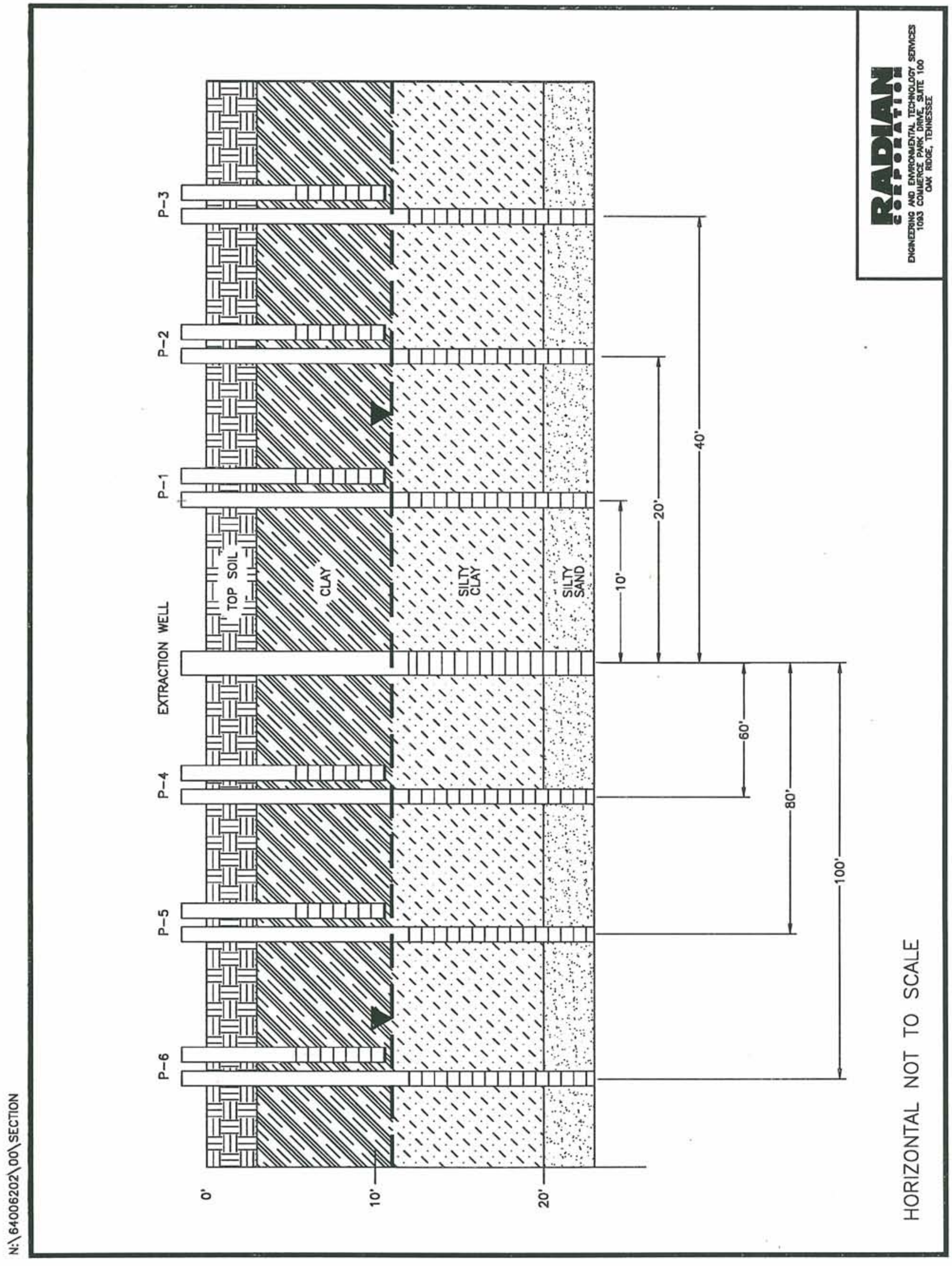

Figure 4-2b. Extraction Well, Piezometer, and Vapor Probe Layout (side view)

- Install extraction well, piezometers, and vapor probes.

- Assemble the wellhead, straw, and fittings necessary for piezometer and probe measurements.

- Attach and assemble the liquid flow totalizer and vapor flow meter.

- Install a hose from the liquid discharge port of the vacuum system to the activated carbon drums and a hose from the outlet of the carbon drum to the storage tank.

- Connect power to the 2-PHASE system and test the voltage to the system and blower motor rotation.

- Test the operation of the 2-PHASE equipment.

- Measure baseline groundwater elevations and take baseline groundwater and vapor samples.

4.2.2 Vapor-Phase Equipment Mobilization

The GPR, ancillary equipment, and Skid #2 will be shipped to the site and spotted near the 2-PHASE system. An office trailer, other supplies, and a tent structure will be delivered to the site.

The following steps will be performed to set up for the pilot test. The duration for the set-up and tie-in to the 2-PHASE vacuum extraction system is seven to ten days.

- Spot all equipment on the site. Rope off the site to restrict access. Establish a location for vehicles and materials.

- Connect power to the GPR system and test the voltage to the systems and the blower motor rotation.

- Set up the GPR system. Install, check, and calibrate the on-line monitoring instruments (pH probe, vapor flowmeters, etc.).

- Set up the tent assembly.

- Secure and anchor trailer.

- Mix nutrients and charge the system with liquid media.

- Test the operation of the GPR system with ambient air. Also test the operation of all ancillary equipment.

- Connect the outlet from the 2-PHASE system to the inlet of the GPR.

- Set up, check, and calibrate the on-line vapor GC monitoring system.

- Operate the system at a flow rate of 10 cfm for 24 to 36 hours with TCE vapor feed to determine the extent of abiotic losses of target contaminants from the system.

4.3 Performance of Test

The following steps will be performed during the 61-day pilot test. The test will begin after the GPR start-up period as outlined in Section 4.3.2 below.

4.3.1 2-PHASE Performance

The following steps will be taken during the performance of the 2-PHASE system.

- Start 2-PHASE system and allow warm-up of 2-PHASE equipment. Check operating conditions during warm-up. Document liquid totalizer reading.
- Attach vacuum hose to system and wellhead. Insert the straw into the well above the water table and take initial soil vapor sample. After taking the vapor sample, lower the straw slowly to evacuate liquid from the well bore. When all liquid is evacuated, open aspiration air valve and seal the wellhead.
- Ensure proper operation of activated carbon treatment train and filling of storage tank.
- Adjust aspiration air valve to maximize vacuum applied to the well. Check operating conditions of the 2-PHASE system.
- Perform field measurements, record operational data, and take liquid and vapor samples according to the schedule in the sampling and analytical plan.
- Optimize aspiration of extracted liquid, applied vacuum, and operating conditions for the remainder of test. Monitor the fill rate of liquid storage tanks. Run continuously for a 61-day period.

4.3.2 Vapor-Phase System Performance

The following steps will be taken during the performance of the vapor-phase system.

- Inoculate the GPR with one of ENVIROGEN's TCE-degrading microbial cultures. The inoculum will be shipped to the site on ice overnight.
- Operate the GPR with a phenol feed and ambient air influent until the biomass concentration reaches an optical density at 550 nm ($O.D._{550}$) of 1 to 4 (cell density of 5×10^8 to 2×10^9 cells/mL). This is expected to take 1 to 2 weeks.
- After the biomass has grown to a sufficient cell density, start up the 2-PHASE system and begin feeding contaminated vapors to the GPR at a flow rate of 10 cfm. Adjust the dilution air level to obtain a chlorinated (TCE and DCE) concentration not exceeding 500 μg/L to start. Adjust the phenol feed rate, nutrient feed rate, and hydraulic retention time of liquid in the reactor vessel according to the load of chlorinated VOCs fed to system.

- Ensure proper operation of the pH control system and on-line GC system.

- Check the calibration of the GC system three times each week.

- Perform field measurements, record operational data, take liquid samples, and monitor the vapor streams according to the schedule in the sampling and analytical plan.

- Once steady-state performance is reached at the initial feed conditions, steadily increase both the concentration and vapor flow rate supplied to the GPR. After each change, continue to monitor the performance of the system and adjust the co-substrate (phenol) feed rate, nutrient feed rate, and hydraulic retention time of liquid in the reactor vessel according to the load of chlorinated VOCs fed to the system.

- Monitor the fill rate of liquid into storage tank T-104. When the wastewater storage tank becomes 80-90% full, add bleach to the tank to kill the microorganisms and sample and analyze the liquid for disposal.

- Run continuously for 61 days.

- Perform a "killed control" run lasting 12 to 24 hours at the end of the 61-day testing period by increasing the pH of the system to 10. Ensure that the phenol in the reactor is consumed before conducting the "killed control" experiment.

4.4 <u>System Shutdown and Equipment Demobilization</u>

4.4.1 2-PHASE System Shutdown

The following steps will be taken to shut down the 2-PHASE system and prepare for demobilization.

- Document all final operating conditions and field measurements.

- Decontaminate vacuum system and PVC piping by running clean water through the system.

- Disconnect all equipment and prepare for shipment off-site. Seal carbon drums.

- Sample groundwater in the well.

The following steps will be followed to demobilize equipment and materials from the site.

- Secure the 2-PHASE system and equipment and tow off-site.

- Return activated carbon drums to Westates Carbon for disposal.

- Perform site inspection with a representative of Base Environmental Office.

4.4.2 Vapor-Phase System Shutdown

The following steps will be taken to shut down the GPR system and prepare for demobilization:

- Document all final operating conditions and field measurements.

- Add bleach to the media in the GPR to kill the microorganisms.

- Transfer the contents of the GPR into the wastewater storage tank and sample the water to ensure the water is safe for disposal.

- Decontaminate the GPR by running clean water and fresh air through the system.

The following steps will be followed to demobilize equipment and materials from the site:

- Secure the GPR system, Skid #2, analytical GC, and ancillary equipment and ship off-site.

- Perform site inspection with a representative of Base Environmental Office.

5.0 SAMPLING AND ANALYTICAL PLAN

To assess the effectiveness of the 2-PHASE vacuum extraction and vapor-phase bioreactor systems, field measurements will be performed, system operating conditions will be recorded, and liquid and vapor samples will be taken. The following sections describe the measurements and sampling to be performed and the purpose of these activities.

5.1 <u>Field Measurements</u>

5.1.1 2-PHASE System

Table 5-1 will serve as the field data sheet for field measurements of the 2-PHASE system and indicates the data to be recorded. 2-PHASE system field measurements will indicate the effects of the 2-PHASE system on the subsurface formation and will consist of the following:

- Groundwater levels in the six liquid piezometers will be used to measure drawdown of the static water table, as well as background water levels in surrounding monitoring wells.

- Vacuum measurements of the six vapor probe tests and piezometers will be taken to measure the magnitude and extent of vacuum influence.

- Extracted liquid flow volume will be used to evaluate liquid and contaminant extraction rates.

- Extracted vapor flow rate will be used to evaluate vapor and contaminant extraction rates. Spot real-time measurements of total VOCs may also be made with a portable direct-reading instrument.

- Vacuum readings in the vapor probes will be used to observe any changes with time.

5.1.2 Vapor-Phase System

Table 5-2 will serve as the field data sheet for field assays and measurements to be performed on the GPR system. The information gained from the field assays and measurements will be used to assess the performance of the GPR system and make corrections and changes to important operating parameters. The field assays and measurements, along with the schedule during steady-state operation, will consist of the following:

- biosolids concentration in the GPR system via analysis of protein (standard BCA Protein Assay) and O.D.$_{550}$ (Spectronic 20 spectrophotometer) (3 times/week);

- phenol concentrations in the GPR system (see Appendix A for method) (5 times/week);

- ammonia nitrogen and ortho-phosphate concentrations in the GPR system using test kits (see Appendix A for methods) (3 times/week);

- phenol specific activity of microorganisms in GPR system (see Appendix A for method) (3 times/week);

Table 5-1

2-PHASE System Field Measurements Data Sheet

Actual Schedule			Water Level (ft)						Piezometer Vacuum (in. WC)					
Day	Time	Total Hours	P1	P2	P3	P4	P5	P6	P1	P2	P3	P4	P5	P6

Table 5-1

(Continued)

Actual Schedule			Vapor Probe Vacuum (in. WC)												Liquid Flow (gal)	Vapor Flow Rate (cfm)
Day	Time	Total Hours	V1A	V2A	V3A	V4A	V5A	V6A	V1B	V2B	V3B	V4B	V5B	V6B		

Table 5-2

GPR System Field Measurements and Assays Data Sheet

Date	Time	Days After Start-up	Biomass Conc.		Phenol Conc. (μM)	Ammonia Nitrogen (ppm)	Ortho-phosphate (ppm)	Phenol Specific Activity (nmoles/min-mg)	TCE Specific Activity (nmoles/min-mg)
			Total Protein (mg/mL)	$O.D_{550}$					

- TCE specific activity of microorganisms in GPR system (see Appendix A for method) (1 time/week).

Any waste generated during the assay procedures will be stored in a 55-gal drum for disposal at the end of the test. During start-up, a different sampling schedule will be followed, as indicated in the TCE Gas Phase Bioreactor Start-up Protocol shown in Appendix A. However, the same data sheet shown in Table 5-2 will be used.

5.2 Operating Conditions

5.2.1 2-PHASE System

Table 5-3 will serve as the field data sheet for the 2-PHASE system operating conditions and indicates the data to be recorded. Operating conditions of the 2-PHASE system will be monitored. The operating conditions to be recorded include the following.

- system inlet vacuum and temperature;
- wellhead residual vacuum and aspiration valve position;
- seal fluid temperature and pressure;
- exhaust vapor temperature and pressure;
- operating time, potential down time, and repairs; and
- weather conditions, site information, and other comments.

5.2.2 Vapor-Phase System

Table 5-4 will serve as the GPR system field operating parameter log sheet. Important operating parameters are monitored to maintain the equipment in optimal operating condition and also to obtain data necessary for the design and scale-up of the system. The important operating parameters to be monitored include the following:

- inlet and outlet temperatures and pressures;
- inlet and outlet vapor flow rate;
- antifoam, caustic, and nutrient addition rate;
- pH;
- wastewater discharge rate and water make-up.

5.3 Sampling

Quanterra Environmental Services will perform all analyses on liquid samples of extracted groundwater using EPA Method 524.2 in accordance with the existing QAPP and Field Sampling Plan.

Table 5-5 will serve as the field data sheet for analytical sampling and indicates the type of sampling to be performed. The purpose of liquid and vapor sampling is to evaluate the extraction of contaminants from the subsurface, characterize wastes, evaluate treatment effectiveness of the carbon system, and facilitate the evaluation of the 2-PHASE technology for the remediation of this and other sites. A description of the sampling to be performed follows.

Table 5-3

2-PHASE System Operating Conditions Data Sheet

Actual Schedule			System Inlet		Wellhead		Seal Fluid		Exhaust Vapor		
Day	Time	Operating Time (Total Hours)	Temp. (°F)	Vacuum (in. Hg)	Vacuum (in. Hg)	Valve Position	Temp. (°F)	Pressure (psi)	Temp. (°F)	Pressure (psi)	Comments

Table 5-4

GPR System Field Operating Parameter Log Sheet

Date ________

Time ________

Parameter	Reading	Equipment Locator
BSM-A Tank Volume (gal)		T-205
BSM-A Pump (% stroke)		P-203
BSM-A Pump (strokes per minute)		P-203
BSM-B Tank Volume (gal)		T-206
BSM-B Pump (% stroke)		P-204
BSM-B Pump (strokes per minute)		P-204
Inlet Air Flow Rate to TCE Reactor (scfm)		FI-1011
Outlet Air Flow Rate from TCE Reactor (scfm)		None
Inlet Air Temperature to TCE Reactor (°C)		TI-1030
Inlet Air Pressure (psi)		PI-1020
Caustic Tank Volume (gal)		T-102
Caustic Feed Pump (% stroke)		P-102
Caustic Feed Pump (strokes per minute)		P-102
Phenol Tank Volume (gal)		T-101
Phenol Feed Pump (% stroke)		T-103
Phenol Feed Pump (strokes per minute)		P-103
pH Meter Reading		AIC-1030
TCE Reactor Liquid Level		LI-1030
Wastewater Storage Tank Volume (gal)		T-104

Remarks:

Table 5-5

Analytical Sampling Field Data Sheet

Schedule		Extracted Liquid	Extracted Vapor	Liquid Duplicate	Liquid Trip Blank	Vapor Duplicate	Vapor Trip Blank	Groundwater	Soil Vapor	Liquid Phase Carbon Effluent (Storage Tank)
Day	Hour	524.2		524.2	524.2			524.2		524.2

5.3.1 Pre-Test and Post-Test Sampling

Pre-test and post-test sampling will consist of the following:

- Pre- and post-test analyses for VOCs by EPA Method 524.2 will be performed on groundwater from the extraction well. Sampling procedures will be in accordance with the QAPP and the Field Sampling Plan.

- Pre- and post-test analyses for VOCs will be performed on vapor samples from the extraction well. These samples will be collected by operating the 2-PHASE system with the straw above the water table so that only soil gas is extracted.

5.3.2 2-PHASE System Sampling

2-PHASE system sampling will consist of the following:

- Twenty-one extracted groundwater samples (2-PHASE effluent prior to carbon treatment) will be taken over the 61-day test period and will be analyzed for VOCs by EPA Method 524.2 to facilitate evaluation of the 2-PHASE system. In addition to the 21 groundwater samples, 2 duplicate groundwater samples and 1 trip blank per batch will be analyzed for sample quality assurance (QA) and quality control (QC).

- A treated groundwater sample will be taken from the liquid phase carbon drum effluent and analyzed for VOCs by EPA Method 524.2 to evaluate the presence of contaminants prior to discharge of the treated groundwater. These samples will be analyzed by Quanterra Environmental Services with rapid turnaround time so that data can be obtained prior to demobilization.

5.3.3 Vapor-Phase System Sampling

The performance of the GPR will be monitored. The vapor lines will be equipped with liquid traps constructed of glass to eliminate liquid carryover to the GC. Primary standards will be prepared for TCE. The detection limit for TCE is 1 μg/L air. Calibration will be performed using known concentrations of TCE sampled from glass bottles of known volume.

The purpose of the vapor sampling is to evaluate the concentration of TCE from the 2-PHASE system and the performance of the GPR for removing chlorinated VOCs (TCE) from the 2-PHASE system vapor effluent. Three sample points will be monitored on a continual basis: (1) the vapor effluent from the 2-PHASE system, (2) the vapor influent to the GPR (after the dilution point), and (3) the vapor effluent from the GPR.

In addition to on-line vapor sampling, the liquid in the GPR will be sampled every two weeks during the 61-day test period for analysis of the following:

- base neutrals using EPA Method 625;

- total kjeldahl nitrogen using EPA Method 351.3;

- phosphorous using EPA Method 365.2;

- total suspends solids using EPA Method 160.2;

- total organic carbon using EPA Method 415.1.

Sampling procedures will be in accordance with the QAPP and the Field Sampling Plan. During the start-up period, liquid samples will be collected each week. ENVIROGEN's Analytical and Treatability Laboratory will perform the analyses. Strict chain-of-custody will be followed from the time of sampling to the time of analysis. A total of 4 liquid samples will be taken over the 61-day test period, and 2 liquid samples will be collected during the start-up period. In addition to the 6 samples, 1 duplicate sample and 1 trip blank will be analyzed for QA and QC.

Each time the liquid holding tank fills with GPR overflow (approximately every two weeks), the contents will be analyzed for VOCs and semivolatile organic compounds (SVOCs) approximately 24 hours after bleach treatment. The methods used will be EPA Method 524.2 for VOCs and EPA Method SW-8270 for SVOCs. These samples will be analyzed by Quanterra Environmental Services with rapid turnaround time so that the holding tank contents can be properly disposed of. The same analyses will be performed at the end of the test before system demobilization.

6.0 REPORTING

At the conclusion of the pilot-scale test, a Technology Evaluation Report will be prepared summarizing the results of the study. The report will include a discussion of the site background, the equipment design and testing apparatus, analytical data and quality of data for extracted liquid and vapor, groundwater drawdown, extent and magnitude of vacuum influence, liquid and vapor flow rates, contaminant removal estimates, and treated liquid and vapor contaminant concentrations. It will also include an estimate of full-scale system costs.

The Technology Evaluation Report for the pilot test at FE Warren AFB OU 2 will be used to evaluate the effectiveness of 2-PHASE vacuum extraction and vapor-phase biotreatment. The results of these pilot studies will be used to evaluate 2-PHASE vacuum extraction and vapor-phase biotreatment for the remediation of these and other Air Force sites.

6.1 2-PHASE System Evaluation

Contaminant removal rates and the total mass of contaminants removed from the subsurface will be calculated using extracted vapor and liquid flow rate data and average dynamic contaminant concentrations. This information will be used to discuss the remedial effectiveness of the 2-PHASE vacuum extraction and vapor-phase biotreatment technology and forecast removal rates for future use of the technology.

Data describing the extent and magnitude of vacuum influence relative to the distance from the extraction well will be used along with groundwater drawdown data to refine design criteria for well spacing and contaminant removal effectiveness for future remedial designs.

6.2 Vapor-Phase Biotreatment System Evaluation

Biological treatment rates and the total mass of contaminants treated using the GPR will be calculated using vapor flow rate and concentration data. This information will be used to discuss the effectiveness of the GPR biotreatment technology. The Technology Evaluation Report will include a preliminary description of the full-scale system process. The report will also include an economic comparison of the capital and operating costs of a full-scale biotreatment system to treat effluent vapors from a full-scale 2-PHASE vacuum extraction and vapor-phase biotreatment system compared to existing competitive technologies.

Operational data for the 2-PHASE vacuum extraction system and vapor-phase bioreactor system and test apparatus will be used to discuss the technical feasibility of the 2-PHASE vacuum extraction and vapor-phase biotreatment technology and develop criteria for the full-scale application of the technology.

7.0 RESIDUALS MANAGEMENT

At the conclusion of the test, there will be two drums of liquid phase activated carbon, tanks of treated water, a tank of wastewater from the bioreactor (~1200 gal) drill cuttings from piezometer and vapor probe installation, investigation derived waste from sampling and well development activities, a 55-gal drum of waste from wet chemical analyses, and miscellaneous PVC piping for disposal.

The activated carbon drums will be returned to Westates Carbon as hazardous waste. This will be manifested by the Base. Westates Carbon will characterize the carbon and dispose of it at its Parker, Arizona, facility.

The treated groundwater in the storage tank will be sampled for VOCs during the test. Wastewater overflow from the GPR will also be sampled for VOCs and SVOCs during the test following treatment with bleach to kill biosolids.

Investigation derived waste will be drummed at the site. Approximately 6 to 15 drums of these materials are expected. These will be managed by FE Warren AFB along with similar materials from other remedial activities occurring at the Base.

At the end of the test, the aqueous waste from the wet chemical analyses in the 55-gal drum will also be treated by the activated carbon system. The drum will be triple-rinsed with potable water, and the water will be treated by the activated carbon system each time.

It is anticipated that up to 100,000 gal of treated groundwater may be generated during the pilot test. The treated groundwater will be stored in large tanks at the site. Storage is to occur pending resolution of pre-treatment permit and analytical requirements for discharge to the sanitary sewer.

When the test is completed, there will be some PVC pipe from the test apparatus for disposal. This includes the wellhead assembly and the transfer piping from the 2-PHASE system to the liquid phase carbon. These materials will be decontaminated by rinsing with clean water. The FE Warren AFB Remedial Project Manager will be contacted to coordinate the disposal of this material at a local landfill.

8.0 SITE SAFETY AND HEALTH PLAN

This SSHP provides guidance for conducting field activities on a pilot test of the 2-PHASE vacuum extraction and vapor-phase biotreatment of TCE in soil and groundwater to be conducted at FE Warren AFB. The major components of the plan include project organization, hazard analysis, personal protective equipment (PPE), work areas, and emergency procedures. This SSHP must be available on-site as a reference. It is expressly intended that project work be guided by applicable sections of the Occupational Safety and Health Administration (OSHA) standards for general industry [29 Code of Federal Regulations (CFR) 1910] and for the construction industry (29 CFR 1926).

The tasks to be conducted during this project are as follows:

- drill extraction well and install and sample vapor probes and piezometers,
- mobilize project equipment,
- set up equipment and piping,
- perform 2-PHASE vacuum extraction and collect associated data,
- perform vapor-phase biotreatment and collect associated data, and
- demobilize all treatment equipment and piping.

8.1 Project Organization and Health and Safety Responsibilities

This section outlines the project organization and health and safety responsibilities of the team.

8.1.1 Project Manager

Mr. James Machin, P.E., has overall responsibility to ensure that this SSHP is implemented in accordance with federal, state, and local community requirements, as well as with Radian policy.

8.1.2 On-Site Engineer/Safety Officer

Mr. Craig Weber, P.E., will be responsible for on-site health and safety observations and recommendations and for ensuring that this SSHP is followed. Mr. Weber will have authority to stop the project based on his observation of health and safety concerns. Additional duties and/or responsibilities of the engineer are as follows:

- ensure that this plan is read and understood by field personnel prior to beginning the project,
- locate support facilities outside the work area,
- conduct and/or observe air monitoring instrumentation and ensure availability of applicable PPE,
- ensure that personnel observe safe work practices in accordance with this SSHP,
- maintain safety equipment,

- initiate emergency phone calls if an injury or accident requires medical attention,
- upgrade the conditions of this plan as indicated by site conditions or changes in the scope of work,
- report problems to the appropriate supervisor and project health and safety officer,
- maintain the project health and safety file, and
- conduct daily safety briefings with all site personnel.

8.1.3 Field Team Members

Members of the field team are responsible for reading and understanding the SSHP, performing work safely, being aware and alert of signs of exposure to contaminants and/or heat stress, and reporting any unsafe working conditions to their immediate supervisors.

8.1.4 Project Health and Safety Officer

Mr. Tom Weeda, CIH, will serve as this project's health and safety officer. Mr. Weeda will not participate in on-site work but will be available to assist the on-site engineer/safety officer via telephone.

8.2 Hazard Analysis

This section of the SSHP addresses potential on-site hazards that may be encountered during the activities described below. This section discusses tasks that will be performed and associated risks that may be encountered.

8.2.1 General Safety

The presence of heavy equipment, moving/rotating parts, and multiple pieces of equipment while mobilizing and demobilizing can contribute to potential hazards. Prior to the operation of any machinery, all belt and coupling guards associated with motorized equipment will be in place and secured. Personnel should not place anything behind a guard.

During the planning/mobilization phase of the program, base personnel shall be consulted about the location of utility lines and other such underground hazards and obtain all FE Warren AFB-required permits. If excavation or drilling cuttings indicate the possible presence of underground drums or cylinders, operations shall be stopped immediately.

8.2.2 Mechanical Hazards

Hazards while working with mechanical equipment can include cuts, contusions, being struck by or striking objects, being caught between objects, becoming entwined in rotating tools, and falling objects. Care should be taken to eliminate these potential hazards by ensuring that mechanical safeguards are in place, that safe distances between personnel and moving parts are maintained, and that personnel avoid areas where vehicles and equipment are being moved or positioned.

8.2.3 Electrical Hazards

A qualified electrical contractor will provide services to connect the main power to electric equipment. Proper lock-out/tag-out procedures shall be used whenever work is performed on the 2-PHASE vacuum extraction unit or the ENVIROGEN vapor-phase biotreatment unit. Electric shock can occur by direct contact with live wires or with electrical equipment and instruments that are wet or have faulty wiring. Any extension cords used with the equipment should be checked prior to use for cuts or loose connections in the coating protecting the wires.

8.2.4 Slips, Trips, and Fall Hazards

Areas may be muddy and have uneven surfaces. Team members shall be aware of these and other possible hazards, such as equipment on the ground. Falls can occur when climbing ladders on frac tanks. Personnel should always have three points of contact while climbing ladders. If heavy or bulky equipment is needed on the top of the tank, it should be tied to a rope and lifted from below. Railings should be available on the top of the frac tanks.

8.2.5 Fire Hazard

Fires may be caused by excavation of buried gas lines, grass fires, and equipment fires. Precautions should be taken to minimize the potential for fires. No smoking is allowed inside the work area.

8.2.6 Gas and Power Lines

Underground utility lines present in the area shall be located and marked to prevent accidental puncture or breakage during excavation or drilling activities. All contacts (regarding the location of buried lines) with Base and utility company personnel shall be documented. In the event an unmarked buried utility line is damaged, work operations shall halt immediately and all equipment be shut down until the nature of the line is discovered. Should damage occur to a natural gas utility line, all electrical and motorized equipment shall remain shut down, and the contractor shall be responsible for having the line repaired immediately.

8.2.7 Heavy Equipment

The presence of heavy equipment on-site requires that all personnel be constantly aware of the location, speed, and direction of the equipment. To help ensure that employees are aware of this in the area, all equipment shall have backup alarms that operate properly. When working around heavy machinery, employees must make their presence known to the equipment operators. All moving equipment shall consist of road-legal vehicles and shall observe all the traffic regulations at FE Warren AFB. Maintenance shall be conducted on a routine (as needed) basis at the work site or staging area. The work site shall be cordoned off with yellow tape and/or reflective safety flagging to prevent vehicle or pedestrian interference with the work site. Work shall not impede normal traffic ways without orange traffic cones to direct traffic around the work site.

8.2.8 Noise

Work around heavy equipment can result in exposure to excessive noise. Operation of the 2-PHASE vacuum extraction or vapor-phase biotreatment equipment normally does not result in noise levels in excess of the OSHA permissible exposure limit of 90 dBA or the action limit of 85 dBA. The electric generator operating on-site may result in high noise levels and may result in communication difficulties and hearing impairment. It is not anticipated that hearing protection will be needed; however, ear plugs will be available to employees.

8.2.9 Heat Stress

Working in elevated temperatures while wearing PPE may lead to heat stress in the form of heat exhaustion and/or heat stroke. Symptoms of heat exhaustion include dizziness, light-headedness, slurred speech, fatigue, copious perspiration, cool clammy skin, and an increased resting heart rate (110 beats/minute). Symptoms of heat stroke include delirium, fainting, and hot, dry, flushed skin. Heat stroke is a life-threatening condition, and immediate medical attention is required if any symptoms of heat stroke are observed. Heat stress monitoring and prevention procedures will be initiated when ambient temperatures exceed 90°F. Heat stress reduction procedures shall consist of the following:

- Potable water and/or Gatorade™ will be made available to the field team throughout the work day. Field personnel will be encouraged to drink fluids frequently. Field teams working outdoors continuously should break for water at least every hour.

- When temperatures exceed 90°F, all field personnel working outdoors will measure their heart rate at least hourly. If the heart rate exceeds 110 beats/minute, the individual will rest for 10 minutes and drink fluids throughout the rest period. The heart rate should again be measured at the end of the rest period. If the heart rate has dropped below 110 beats/minute, the individual may return to work. If the heart rate exceeds 110 beats/minute, contact the on-site engineer responsible for health and safety.

- Any personnel displaying signs or symptoms of heat stress will stop work and rest for at least 15 minutes. If symptoms persist beyond this rest period, the on-site engineer responsible for health and safety will be contacted. Personnel displaying symptoms of heat stroke, the most serious type of heat-related illness, should immediately be taken to the closest medical facility.

8.2.10 Cold Stress

It is not anticipated that field activities will be conducted under conditions of extreme cold; however, field personnel should be prepared with thermal gear for sub-freezing conditions. Field personnel should be aware that hypothermia can occurs at temperatures of 30-50°F. The symptoms of hypothermia include:

- drop in body temperature,

- extreme shivering,

- disorientation and apathy, and

- muscle rigidity.

Any team member who exhibits any of these signs or symptoms will be removed immediately from field work and be warmed immediately (dry clothes, warm liquids, warm bath, etc.). In severe cases, medical attention will be obtained immediately. If evidence of frostbite exists (reddened skin, pale or waxy white skin, firm skin, numbness), external heat should be immediately applied to the affected area and medical attention should be obtained, if necessary.

8.2.11 Chemical Hazards

Volatile chemicals identified in the soil and groundwater at the OU 2 site in concentrations that have the potential for employee exposures are listed in Table 8-1. The table also lists standards and guidelines for employee exposure and relevant health effects.

Significantly contaminated soils and groundwater, if encountered, will produce elevated airborne concentrations and elevated point source concentrations that are readily detected with direct-reading instruments. Inhalation of volatile organic vapors and skin contact with contaminated soils, groundwater, and equipment are the most likely routes of personnel exposure in the work area. Real-time air monitoring instruments will indicate the presence of vapors.

The 2-PHASE vacuum extraction system extracts soil vapor and groundwater from the well using a high-vacuum pump. The vapor and liquid phases are separated at the unit. The liquids are passed through aqueous phase carbon before being diverted to a storage tank. The vapors pass through a bioreactor vessel prior to release to the atmosphere. Worker exposure to chemical contaminants—if the system is operating as designed—is expected to be minimal. The following safety precautions will be implemented to ensure the protection of employees from potential chemical hazards:

- An air monitoring program, described in Section 8.4, will be implemented in order to measure airborne concentrations of VOCs potentially encountered during on-site work.

- PPE will be provided and required to be worn.

- Chemical-resistant protective clothing and respiratory protection will be available in the event that air monitoring instruments indicate the presence of vapors above 10 ppm in the breathing zone of employees.

- Any chemicals being brought onto the site will have associated Material Safety Data Sheets, which will be reviewed with and available to the field team. Anticipated chemicals include phenol and sodium hydroxide.

- When dispensing or working with phenol or sodium hydroxide, personnel shall wear nitrile gloves, a nitrile apron, and an eye shield. Phenol shall be dispensed using a band-operated drum pump. Precautions shall be taken to minimize splashing. Sodium hydroxide shall be dispensed from its container via gravity through a spout positioned at the bottom of the container. The container shall be positioned at the edge of a bench or table such that the spout clears the edge of the bench or table by no more than 3 in. At no time shall sodium hydroxide or phenol be directly poured from their containers.

Table 8-1

FE Warren AFB Potential Chemical Hazards

Contaminant	OSHA PEL (mg/m^3)	ACGIH TLV (mg/m^3)	Acute/Chronic Effects of Exposure	Skin Designation[a]	Known Suspected Carcinogen
1,2-Dichloroethene	1	10	CNS depressant		✓
Trichloroethylene	200	50	eye irritation, nausea, tremor		✓

[a]A "skin designation" indicates that the dermal route may contribute significantly to the overall exposure. These compounds are readily absorbed by the skin, and extra precautions are necessary to prevent skin contact.

ACGIH TLV = American Conference of Government Industrial Hygienists Threshold Limit Value
OSHA PEL = Occupational Safety and Health Administration Permissible Exposure Limit

8.3 <u>Personal Protective Equipment</u>

The minimum required PPE for all personnel on-site during the field test includes the following:

- hard hat,
- safety glasses with side shields,
- steel-toed work boots: leather (rubber if liquid contamination exists),
- gloves (double-layer disposable nitrile and Silvershield®), and
- hearing protection (when noise levels exceed 85 dBA).

The following additional PPE will be available on-site:

- chemical-resistant clothing: disposable Tyvek® coveralls (coated Tyvek® shall be used in wet areas), and
- half-face or full-face respirator with organic vapor/high-efficiency particulate air cartridges.

PPE shall be used by personnel when engineering controls and work practices are not adequate to reduce employee exposures to acceptable levels. PPE selection shall be based on specific task activities, historical data of contaminants known to exist at the site, site conditions, and the results of the air monitoring program described in Table 8-2. Real-time air monitoring results may require an immediate upgrade in respiratory protection or cessation of work activities until hazardous vapor concentrations disperse. Specific guidance is provided in Table 8-2.

The major chemical exposure hazards at the site result from:

- inhalation of airborne contaminants either in the form of dust or fugitive vapors emanating from the contaminated soils, liquids, or the carbon treatment vessels and
- dermal contact with, or ingestion of, contaminated soils and liquids.

PPE requirements for each task may be modified after the on-site and project safety officers discuss and concur. Guidance regarding PPE inspection and respirator cartridge replacement frequency can be found in the FE Warren AFB SSHP.

8.3.1 Temperature Limitations

Chemical-resistant clothing and respirator use can cause employees to fatigue rapidly and will inhibit body cooling. Personnel shall be instructed to pace themselves to ensure adequate rest periods.

8.3.2 Training and Medical Surveillance Requirements

All personnel are required to be in compliance with OSHA 29 CFR 1910.120, Hazardous Waste Operations Health and Safety Training Requirements. All field team personnel must have had a physical examination with medical clearance within the last year to conduct this work.

8.3.3 Recordkeeping Requirements

Records of training and medical surveillance shall be maintained for the project records.

Table 8-2

Hydrocarbon Response Criteria

Organic Vapor Concentrations and Specific Contaminant Monitoring	Sampling Frequency	Action Taken
OVC < 10 ppm for >2 minutes	Every hour thereafter or upon recommendation of the health and safety officer	Continue work with required minimum PPE for the field activity.
OVC 11-100 ppm for >2 minutes	Every 15 minutes	All personnel on-site will don half-face or full-face air-purifying respirator equipped with organic vapor/HEPA filter cartridges. All personnel on-site will don Tyvek® coveralls.
OVC 101-500 pmm >2 minutes	Every 10 minutes	All personnel on-site will don full-face air purifying respirator equipped with organic vapor/HEPA filter cartridges.
OVC >500 ppm or Benzene >50 ppm		Stop work. Work crews position themselves upwind of site. Re-evaluate in 15 minutes. Contact field coordinator and project health and safety officer. NOTE: These same actions are to be taken if lower explosive limit is >20%.

HEPA = high-efficiency particulate air
OVC = organic vapor concentration
PPE = personal protective equipment

8.4 Air Monitoring and Safe Work Practices

8.4.1 Air Monitoring

Air monitoring will be performed at the outlet of the system and in the breathing zone of the field team to determine the potential for worker exposure. Monitoring will be performed in the breathing zone of the worker nearest the source(s) of air contaminants and their discharge to the atmosphere. The following precautions will be taken in order to ensure that field personnel are not being overexposed to organic vapors.

- If discharging extracted vapors directly to atmosphere, the extraction system will be equipped with an exhaust stack that is at least 10 ft above grade.

- All work associated with the extraction testing will be performed upwind of the exhaust stack whenever possible.

8.4.2 Organic Vapor Concentration

Organic vapor concentrations will be measured with a photoionization detector and direct-reading detector tubes. Table 8-2 summarizes the actions that will be taken in response to monitoring results.

8.5 Work Zones and Decontamination Procedures

The on-site engineer/safety officer is responsible for establishing the appropriate work zone designation and defining the zone in accordance with this plan.

8.5.1 General Work Zone

A general work zone shall be delineated by the on-site field engineer/safety officer through the use of barricade tape or other appropriate barrier. A general work zone is characterized by an absence of uncontrolled chemical substances or materials.

8.5.2 Exclusion Zone

An exclusion zone (EZ) shall be established to minimize the risk of chemical exposure and contaminant migration off-site and to restrict unauthorized personnel from entering potentially dangerous work areas. No eating, drinking, or smoking shall be allowed in the EZ. The EZ will be established using barricade tape.

8.5.3 Contamination Reduction Zone

A contamination reduction zone acts as a buffer zone allowing personnel egress to and from the EZ. All contaminated clothing and equipment is disposed of or decontaminated in this zone.

8.5.4 Support Zone

A support zone will be established outside of the EZ. This zone is considered free of chemical and physical hazards and may be used for observational purposes.

8.5.5 Decontamination Procedures

Decontamination of equipment shall be conducted in the general work area. This includes decontaminating or isolating equipment before placing it in sampling vehicles. Decontamination of sampling equipment shall occur before removing PPE. Due to the nature of the site and the scope of work, it is not expected that decontamination of PPE or personnel will be needed to protect worker health. If personnel come in contact with groundwater, the affected area should be thoroughly washed with soap and water.

8.6 Emergency Response

Emergency procedures listed in this plan are designed to instruct the field team in handling medical emergencies.

8.6.1 Injuries

Medical problems that may occur on-site need to be handled competently and quickly. Each field team member shall know the location and contents of the first aid kit supplied to them. Each field team member shall be aware of the instructions and information given below.

- Become familiar with the emergency telephone numbers in Table 8-3.
- Seek professional medical attention for personnel who are not breathing, bleeding severely, experiencing intense pain, or unconscious. Each member of the site team will know how to call for an ambulance (on- and off-base).
- If you get chemicals or dust in your eyes, flush them with water for 15 minutes.
- Do not remove objects that are stuck in the eye. Always seek medical attention for eye injuries.
- Treat all burns (chemical or thermal) by running cold water over the affected area.
- Report all injuries to the project safety officer and/or your supervisor.
- In case of any emergency, notify FE Warren AFB Environmental Management.

8.6.2 Emergency Equipment

The following emergency equipment shall be available for immediate use. All field personnel shall be made aware of the location of the emergency equipment.

- phone list and directions to the nearest emergency care center,
- first aid kit,
- one 10-lb ABC-rated fire extinguisher,
- eye-wash station, and
- 5 gal of potable water.

8.6.3 Emergency Phone List

Table 8-3 is a list of emergency phone numbers.

8.6.4 Hospital Directions

A map to the local city hospital (United Medical Center) is provided in Figure 8-1.

The base hospital (Building 160) is located on Alden Drive.

Table 8-3

Emergency Phone Numbers

Emergency Agency		Phone Number
Base Contacts: Barry Mountain		(307) 775-3468
Police		1100
Fire Response		On-Base 117 Off-Base 911
Ambulance		118
Hospital:	FE Warren AFB Hospital - 90th Medical Group	2777
	United Medical Center Cheyenne, Wyoming	(307) 634-2273
Medical Emergency 24-hour Toxicological Information Service		(513) 421-3063
Center for Disease Control		(404) 639-3311
CHEMTREC		(800) 424-9300
Project Health and Safety Officer: Tom Weeda, CIH		(919) 461-1100

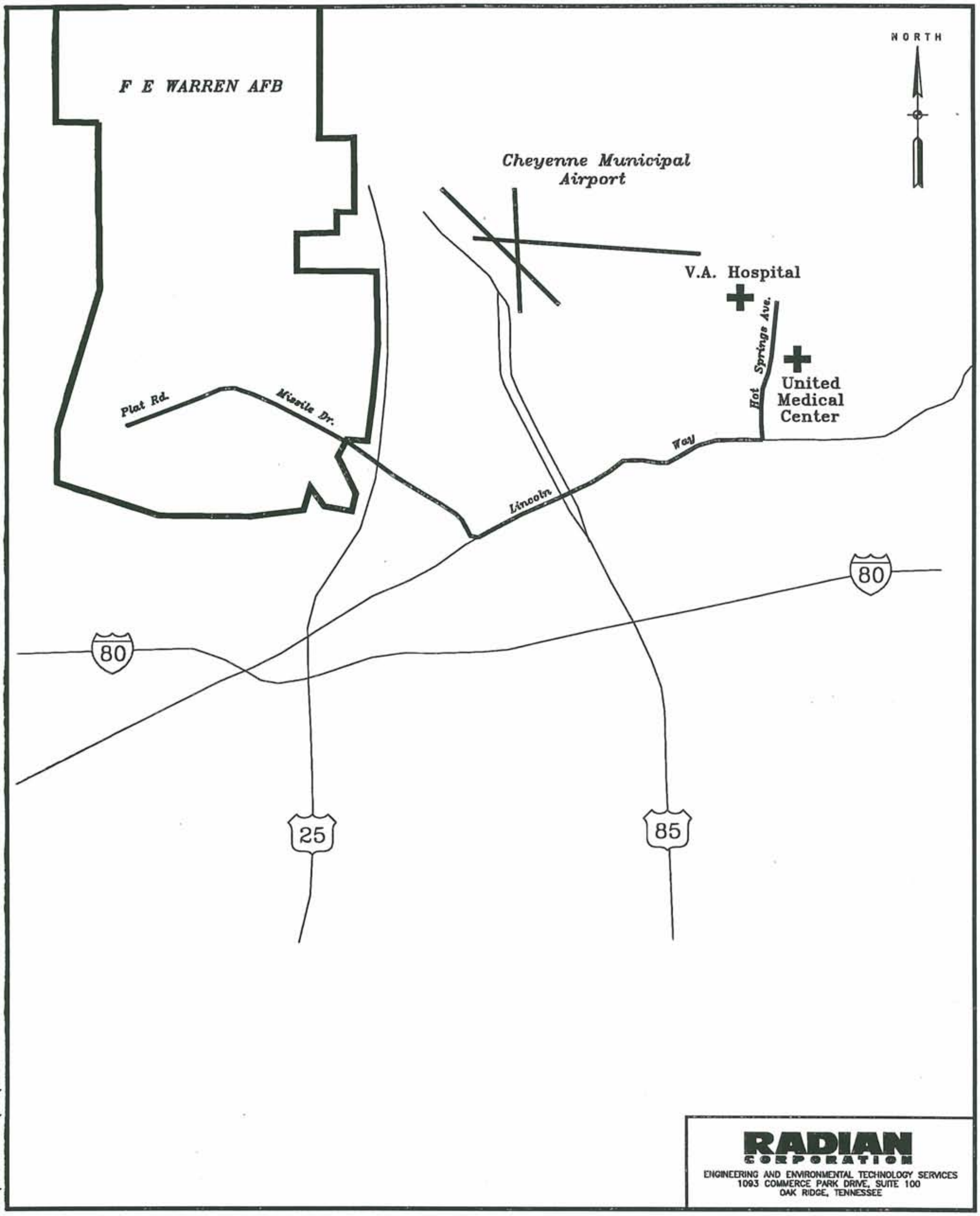

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Figure 8-1. Map to Local City Hospital

9.0 SCHEDULE

The schedule for all activities related to this pilot-scale test is presented in Table 9-1. The schedule includes anticipated task start dates and task completion dates, as well as a relative scale of time in the event of an unforeseen change in the schedule.

Table 9-1

FE Warren OU 2 2-PHASE Extraction and Vapor-Phase Biotreatment Pilot Test Schedule

Activity	Start Date	Completion Date
Prepare and submit work plan	1 June	29 June
Receive work plan comments	29 June	24 July
Complete and submit final work plan	24 July	4 August
Order/reserve carbon drums, generator, truck, sampling and measurement equipment	24 July	21 August
Install extraction well, vapor probes, and piezometers	21 August	25 August
Mobilize equipment	14 August	21 August
Set up for test	14 August	30 August
GPR start up	30 August	11 September
Run test	11 September	10 November
Dismantle apparatus	13 November	14 November
Demobilize equipment and materials	13 November	16 November
Discharge water and return frac tanks	14 November	15 November
Review field and analytical data	10 November	8 December
Prepare and submit draft Technology Evaluation Report	10 November	28 December
Receive comments	28 December	31 January
Prepare and submit final Technology Evaluation Report	31 January	28 February

APPENDIX A

A.1 DESCRIPTION OF FIELD ASSAYS AND MEASUREMENTS FOR VAPOR-PHASE BIOTREATMENT SYSTEM

A.1.1 Wet Chemical Analyses

A variety of analyses will be used to track key operating parameters during the project. Primarily, these methods are used to track the concentrations of biomass, nutrients, and chemicals critical to stable system operation.

Biomass. Biomass concentrations will be determined either by monitoring turbidity (absorbance at 550 nm) or by determining protein concentration (BCA Protein Assay, Pierce Chemical). Both methods will quantify absorbance using a Spectronic 20 (Bausch & Lomb). Periodic correlations between turbidity and protein concentration will be determined to ensure the accuracy of the turbidity method. Biomass concentrations in suspensions that are flocculent or nonhomogeneous will be determined exclusively using the protein assay method.

Ammonia. Ammonia concentrations will be determined using a colorimetric kit specific for ammonia (Aquarium Pharmaceuticals, Inc., Chalfont, Pennsylvania). A 5-mL sample will be added to a test tube containing 8 drops of a modified Nessler Reagent. The color generated will be compared to a test chart. If required, samples were diluted to fall within the range of the assay, 0 to 7 ppm ammonia.

Phosphate. Phosphate concentrations will be determined in the field using a colorimetric kit specific for orthophosphate (Hach Co., Loveland, Colorado). A 0.5-mL filtered sample will be added to a rinsed test tube followed by 4.5 mL of distilled water to give a total volume of 5.0 mL. One phosver 3 phosphate reagent powder pillow will be added to the sample and the contents of the tube mixed. The color generated will be compared to a color wheel. If required, samples will be diluted to fall within the range of the assay, 0 to 50 ppm $P0_4^{3-}$.

Phenol. Phenol concentrations will be determined using a modified calorimetric assay. A 1-mL sample is transferred to a plastic microcentrifuge tube with 25 μL of 2% 4-aminoantipyrene and 50 μL of 2 N NH_4OH. The contents are mixed, 25 μL of 8% $K_3Fe(CN)_6$ are added, and the contents are mixed again. The tube is then centrifuged to pellet out suspended solids, and the absorbance of the supernatant is determined at 500 nm using a spectrophotometer. The absorbance is then compared to a standard curve. The concentration range of the assay is between 5 and 100 μM (approximately 0.5 and 10 ppm). If the concentration is above this range, the sample is diluted.

A.1.2 Phenol and TCE Specific Activity

Phenol and TCE specific activities are determined using standardized assay methods developed at ENVIROGEN.

Phenol. 10 mL of biosolids suspension is removed from the reactor system. Biomass concentrations are determined by either monitoring turbidity (absorbance of 550 nm) or determining the protein concentration directly (BCA, Pierce Chemical). 0.1 mL of 10 mM phenol in water is added to the 10 mL suspension of biosolids (100 μM final concentration). The contents are mixed using a stir-plate. At defined time intervals, 1 mL aliquots are transferred to microcentrifuge tubes containing 50 μL of 2 N NH_4OH and 25 μL of 2% 4-aminoantipyrene. The tubes are closed and mixed. 25 μL of 8% $K_3F3(CN)_6$ are added to each tube followed by mixing. The tubes are centrifuged to pellet out suspended solids, and the absorbance of the supernatant is determined at 500 nm using a spectrophotometer. The decrease in absorbance is then correlated with phenol concentration. The decrease in concentration per volume of mixture is divided by the biomass concentrations to obtain the specific activity, expressed in units of nmoles/minmg protein.

TCE. A suspension of biosolids is removed from the reactor and is added to a 50-mL serum bottle. Biomass concentrations are determined by either monitoring turbidity (absorbance at 550 nm) or protein concentration directly (BCA Pierce Chemical). 10 mL of 40 mM TCE dissolved in dimethylformamide is then added to the bottle, which is immediately sealed with a Teflon®-lined septum and shaken. A negative control, consisting of either buffer alone or buffer with killed cells, is used to monitor abiotic losses. Sodium azide (0.1%) or adjustment to pH 10 is used to inhibit biological activity in the killed control samples. At defined time intervals, 10 μL of air headspace is withdrawn for GC quantitation. Concentrations are calculated in comparison to external standards. The decrease in concentration is determined as a function of time and biomass concentration. TCE specific activity is expressed in units of nmoles/minmg protein.

A.2 TCE GAS PHASE BIOREACTOR START-UP PROTOCOL

The following steps for the TCE gas phase bioreactor start-up are:

- Fill reactor with water to about 3/4 height of overflow wier.
- Make sure make-up water feed, nutrient feed, and phenol feed pumps are off.
- Set the air flow at 10 cfm.
- Make sure the mixer, foam control systems, and pH control (set point of 6.8 to 7.0) system are on.
- Add nutrients to the reactor.
- Remove two samples of bacterial inoculum, place in 15-mL sterile centrifuge tubes, and store at 4°C until shipment to ENVIROGEN. Record total volume of inoculum to be added.
- Add inoculum to reactor. Allow sufficient time for the inoculum to mix and record the $O.D._{550}$ using Spectronic 20. Remove a 1-mL sample for protein analysis and store at 4°C until analysis is performed.
- Check phenol concentration in reactor. If concentration is <100 μM, slowly add 200 mL of 88% phenol directly to reactor to give about 1000 μM (100 ppm) final concentration.

- Monitor phenol concentration at 30 to 60 minute intervals until phenol is degraded to < 100 μM. Initially, dilutions will be required to obtain the concentration range for the assay (< 100 μM). The time interval for samples can be adjusted depending on the rate of phenol degradation. Record concentration and time to obtain a crude degradation rate.

- Once the phenol concentration is < 100 μM, determine the $O.D._{550}$ using Spectronic 20. Remove a 1-mL sample for protein analysis and store at 4°C.

- Start the phenol feed pump and monitor the phenol concentration in the reactor at 30 to 60 minute intervals. At the designed flow rate, the phenol concentration would be about 500 μM (50 ppm) after 1 hour if there is no degradation. The bacteria could be killed if the concentration exceeds 2000 μM (200 ppm). **It is critical that samples are collected to ensure that excess phenol does not build up in the reactor.** If there is > 100 μM phenol in the reactor, turn off the phenol feed pump, monitor and record phenol concentrations at intervals, and resume phenol feed once the phenol is dissipated in the reactor. Continue cycle until continuous feed does not result in phenol build-up in the reactor.

- When the $O.D._{550}$ reaches 1, start make-up water feed, nutrient feed, and TCE feed. Start out at a combined chlorinated (TCE and DCE) feed concentration of 500 μg/L.